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SATCON2: Executive Summary

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1. Introduction

About twenty years ago, rapid advances in technology led to the viability of light-emitting diodes (LEDs) as outdoor lighting. With compelling operational and economic reasons to make the shift from legacy gas-discharge systems, communities around the world began installing white LEDs as their lighting of choice. In time, the side effects of the vastly increased sky glow and blue-rich spectral distribution of white LEDs became apparent, negatively impacting not only ground-based professional and amateur astronomy but also casual appreciation of the sky, flora and fauna, and human health.

Today, we are in the initial years of an analogous watershed moment, this time not on the ground but in space. The rapid development of efficient and in one case reusable rockets by private-sector companies has made Earth orbit no longer the exclusive realm of national agencies like NASA, and a steadily increasing number of entities is now launching both people and hardware into space. The result is exponential growth in the density and variety of satellites at a wide range of altitudes. As the glowing nighttime landscape on Earth has been transformed over the past two decades, so the sky is now being similarly transformed.

It is incumbent on all who use space and the night sky as a resource — professional and amateur astronomers, satellite operators, policymakers, environmentalists, people who observe the night sky and who preserve their culture in stories in the stars, and more — to consider the myriad impacts on humanity of the industrialization of space and to establish a shared vision for the use of space that supports and respects all its users.

Many efforts today to address the impact of rapidly growing light domes over cities and towns are reactive to already-deployed networks of white LEDs. In the realm of low-Earth orbit (LEO), there is a window of opportunity — albeit narrow and closing — to address the impact of thousands of new satellites proactively. The SATCON workshops are meant to set the foundation for this work.

2. Goals and Structure of SATCON2

The SATCON1 workshop, held 29 June–2 July 2020, presented ten recommendations for the astronomy community and the satellite industry aimed at mitigating the impacts of large numbers of satellites on optical astronomy.

Three recommendations for observatories noted the need to develop comprehensive software tools to mask and remove satellite trails from images, predict satellite passages through fields of view, and analyze the scientific impact of corrections to affected data.

Four recommendations for satellite operators encouraged careful up-front design to minimize brightness and ensure it varies slowly, avoiding glints or flares to the greatest extent possible.

Three recommendations for observatories and operators in collaboration called for a comprehensive network of satellite observers to measure the impact and effectiveness of satellite design on brightness, as well as for improved positional information to allow more accurate prediction of satellite passages.

The primary goal of SATCON2, held 12–16 July 2021, was to develop specific, implementable paths to carrying out these recommendations. The workshop's two additional goals were to engage a considerably wider group of stakeholders in the conversations than had been present at SATCON1 and to explore existing policy frameworks, generating ideas for the development of policies capable of addressing an entirely new era in the exploration and use of space.

To this end, we structured SATCON2 in much the same way as SATCON1. We charged four working groups (WGs) to prepare draft reports relevant to the workshop's goals and to present their findings at the workshop itself. The 12–16 July 2021 sessions then informed the preparation of the final versions of the four reports as well as this executive summary.

Two of the WGs, Observations and Algorithms, explored some SATCON1 recommendations directly. The Community Engagement WG brought many new voices and perspectives to the issue, and the Policy WG examined regulatory framework and mitigation approaches from national, international, and industry viewpoints. The full reports of these WGs, authored by their members, are provided as appendices. In this executive summary, authored by the SOC[1], we present distillations of the findings and conclusions in the sections below.

3. Recommendations of the Working Groups

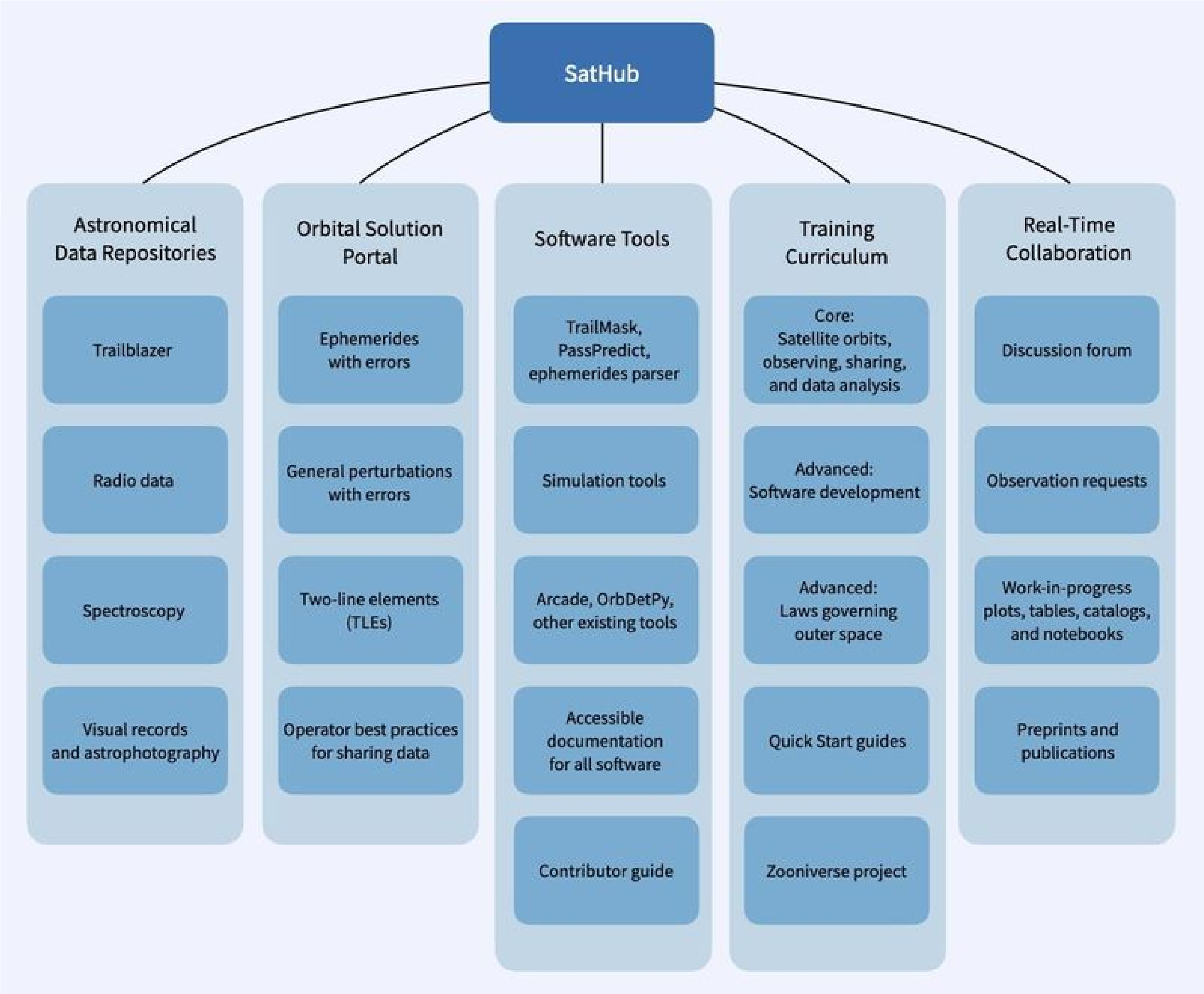
3.1. Observations Working Group

The Observations WG Report outlines implementation steps for SATCON1 Recommendations 8, 9, and 10, and takes the liberty of expanding the scope beyond mid-latitude optical/near-infrared (NIR) astronomy, because LEO satellite proliferation impacts observers worldwide at all latitudes and wavelengths. The report's authors, a broad group composed of astronomers, educators, entrepreneurs, satellite operators, and more, endorse and aim to build on the findings of the Dark and Quiet Skies for Science and Society Report and Recommendations (2020). We identify that a likely avenue for implementation may be through the establishment of a new IAU[2] Centre for the Protection of the Dark and Quiet Sky from Satellite Constellation Interference, and emphasize that all steps in our report require significant overall resources on as fast a timescale as possible.

It is difficult to make accurate predictions of the location or brightness of a satellite, yet this knowledge is essential to quantifying and mitigating scientific and broader impacts. Several ad hoc observing campaigns have characterized initial impacts of growing LEO satellite constellations on astronomy, but these are poorly funded and do not scale effectively. Central to our proposal, therefore, is a new comprehensive, worldwide, coordinated, and public observing initiative: SatHub.

3.1.1. Establish SatHub

The main components of SatHub are Astronomical Data Repositories, an Orbital Solution Portal, Software Tools, a Training Curriculum, and support for Real-Time Collaboration. Each of these encompasses several critical modules — everything from queryable image databases to a developer guide for software contributors, to quick start recipes for observers equipped with various hardware, to a mechanism for submitting requests to observe satellites in a particular way. The Observations WG Report focuses on Astronomical Data Repositories, a Training Curriculum, and the Orbital Solution Portal, and we defer to the Algorithms WG Report and future IAU Centre for Software Tools and Real-Time Collaboration, respectively. SatHub components and organization are shown in the figure below.



Astronomical Data Repositories support upload, query, preview, and download of most FITS optical/NIR observations and include services like Trailblazer, an open data repository of astronomical images containing satellite trails, which should launch in early 2022. They must also encompass wavelengths outside optical/NIR including radio, space-based observations from observatories in LEO, non-image data products including spectra, and other formats including visual sightings/DSLR images. Broad participation in SatHub is critical to minimizing duplicated effort and disseminate current impacts from a rapidly changing LEO satellite population.

3.1.2. Build a Training Curriculum

Sharing data products and establishing SatHub are critical, but we must also train observers of all kinds to contribute to the global LEO satellite monitoring campaign. To accomplish this, we outline a training curriculum that can be adapted to suit a variety of observers. It includes a core curriculum with an introductory module and modules on observing satellites, reporting/sharing observations, and image/data analyses. In addition, we outline advanced modules: software development, radio astronomy, and laws governing outer space. Finally, it will include appendices with Quick Start Recipes for astrophotographers, smaller telescope users, and larger research-grade telescope users, as well as links to related citizen science projects.

3.1.3. Best Practices for Operator Public Data Sharing

The position of a satellite at a future time is forecast with a propagator algorithm that uses an orbital solution from the recent past. The SATCON1 Report concluded that it is essential for satellite operators to provide prompt, accurate, updated, and publicly available orbital solution data in a standardized way. To achieve this, we propose and justify four key implementation steps:

1. Operators should publicly provide orbital solutions every 8 hours or whenever a maneuver happens, whichever is first, and must include reasonable estimates of uncertainties with all orbital solutions.
2. In addition to orbital solutions, operators should publicly provide any other relevant metadata that may assist observers in assessing impacts on observations at all wavelengths. These may include, but are not limited to, reflectivity, bidirectional reflectance distribution function (BRDF), effective isotropic radiated power (EIRP), transmission bandpasses, and nominal flux density at different frequencies.
3. Operators should adopt standard formats for both ephemeris-style orbital solutions (state vectors of position and velocity data) and general perturbation-style orbital solutions (time-averaged Keplerian elements that include atmospheric drag that are presently provided in TLE[3] format). We suggest a format like the plain text NASA Modified ITC Ephemeris format that SpaceX presently uses for the former, and strongly endorse the Celestrak-recommended Orbit Mean-Elements (OMM) format from Consultative Committee for Space Data Systems (CCSDS) 502.0-B-2 for the latter.
4. We must promptly establish a public Orbital Solution Portal website as part of SatHub. Satellite operators should pay for the hosting and upkeep of this website. It should retain rather than overwrite past orbital solutions and provide an easy lookup interface for data retrieval, and it should include an open source software tool that allows users to translate between ephemerides, general perturbations in the new OMM format, and old-style TLEs.

3.2. Algorithms Working Group

SATCON1 noted that new software tools will be critical to dealing with the challenge of observing in the era of satellite constellations. The Algorithms WG considered the specific approaches recommended by SATCON1 and developed them into specific high-level software requirements. Each of the proposed packages will take a great deal of time and effort to create, partly because of the complexity of the problem they need to solve, and partly because they must serve multiple communities with varying levels of software familiarity. The group emphasizes that in the end no set of software tools will allow astronomers to fully recover the data affected by satellite trails. The WG recommends that a number of specific software efforts are needed, and while the entire community is expected to contribute, coordination is needed to provide interoperability, end-to-end functionality, documentation and long term support; SatHub will provide a natural home for that effort. Some relevant software which already exists is noted in the report.

3.2.1. Create Test Datasets

An urgent task is to define a range of test datasets which can be used to validate the software tools that are developed. These datasets should include satellite streaks captured by instruments with a range of apertures, exposure times, pixel sizes and background characteristics. Cases where pairs of observations of the same sky region are available with and without trails will be especially useful. A test satellite ephemeris database will also be needed to exercise pass prediction tools in a controlled way.

3.2.2. Create TrailMask

The proposed TrailMask software effort needs to recognize and flag satellite trails in optical/NIR image data (spectroscopic data is a different challenge). It must handle mosaic imagers and probably also cases where the detector is dithered, and should not confuse satellite trails with asteroid trails or other valid data. Programmatic and web-based interfaces will be needed to support different user communities. TrailMask should be able to run “blind” with little prior information, or “seeded” where locations of predicted trails are input.

3.2.3. Create PassPredict

In the era when satellite trails are frequent but not ubiquitous, it will be important to know when particular astronomical targets will be affected by trails and when they are expected to be free of them. PassPredict would use a satellite ephemeris database to check when particular areas of sky will be affected by satellite passes. We concluded that the accuracy of these predictions may be good enough to say when a satellite will be in the field of view but not good enough (at least if only low-accuracy TLEs are available) to say where the trail will be in that field of view. Statistical approaches to determine areas of sky which have a lower density of trails at a given time will also be useful, and complementary to the specific predictions.

3.2.4. Create Simulation Tools

The TrailMask and PassPredict tools are aimed at the typical working observational astronomer (professional or hobbyist) trying to make specific new observations. But as a community we also need to assess the overall impact, current and future, of satellite trails on our science, and this will require significant simulation efforts. Individual observatories will also want to carry out simulations to assess impacts on their programs. We propose developing software which will create images with simulated satellite trails at various levels of fidelity, as well as software which will automatically assess collections of such images to quantify things like the percentage degradation in source detection efficiency as a function of brightness.

3.3. Community Engagement Working Group

The Community Engagement WG aimed to engage a broad swath of diverse stakeholders in dark skies and near-Earth space beyond professional astronomy alone, who are impacted by large “mega-constellations” of tens of thousands of LEO satellite constellations. The Community Engagement WG consisted of 22 members across 23 time zones including professional and amateur astronomers, members of sovereign Indigenous/First Nations communities, dark-sky advocates, planetarium professionals, and environmental/ecological non-governmental organizations. Community Engagement WG members conducted scores of conversations, surveys, listening sessions, outreach, and meetings with members of many constituencies and interest groups that were potentially or already impacted by LEO satellite constellations.

For SATCON2, the Community Engagement WG focused on five specific constituencies, who shared their feedback, needs and recommendations at the workshop.

1. Astrophotography and Astro-Tourism
2. Amateur Astronomy
3. Indigenous Communities and Perspectives
4. Planetariums
5. Environmental and Ecological Concerns

We acknowledge that many constituencies and perspectives were not included through the Community Engagement WG, and that what we share here does not represent all members of any subgroup. We nevertheless note these common themes that recurred and resonated across the five subgroups:

- The skies and space belong to everyone. Space is a global commons.
- All people are impacted by changes in the sky. Nearly all consulted for SATCON2 had already noticed a dramatic rise in satellite constellation sightings in the past two years, and were worried. Many communities see the unchecked actions of space actors as colonization expanded to a cosmic scale during a time of global crisis.
- The sky must be considered part of the environment and the current National Environmental Policy Act (NEPA) exemption for the satellite constellation industry must end.
- Ecosystems depend on the night sky and on each other.

Collectively, the Community Engagement WG offers the observations and recommendations outlined below.

3.3.1. Duty to consult

Satellite operators must first consult all impacted groups, including the sovereign American Indian/Alaska Native nations and global Indigenous communities before launching satellites. Industry must fully consider the concerns of Indigenous nations, including sovereignty, transparency, written agreements, and jurisdiction of treaties in space.

3.3.2. Need for more information and communication

Communities want more information and dialogue. Astronomers and other parties concerned about the impacts of LEO satellite constellations need to engage, listen, share, and act with affected constituencies, government agencies, and cultural, grassroots, and political leaders.

Decision-makers and private satellite operators must intentionally invite the voices and groups that have historically been excluded from the power structure and decision-making regarding space activity.

3.3.3. Engage with industry

Astronomers and other interested and affected groups need to continue to engage with the satellite industry to build relationships and find common ground.

3.3.4. Recognize and rebalance power structures

Decision-makers and advocates for regulation of LEO satellites should recognize the economic, legal, and political structures that continually affect technology choices. The regulatory process must take those power structures into account to optimize societal and environmental benefit with equity — power over a global commons comes with responsibilities to the global good.

3.3.5. Learn from the past

History offers valuable lessons on many issues with satellite constellations including environmental concerns, loss of millenia-old practices, and the painful legacies of colonization. The past century in particular offers ample examples of disruptive technologies that have been developed first and regulated only later, with varying degrees of cost, benefit, risk, and impact, e.g., telephones, trains/planes/cars, fossil fuels, and the Internet itself. Examples of global challenges requiring international collaboration include damage to the ozone layer, for which corrective action has been largely successful, and climate change, for which a global course of corrective action has remained elusive.

3.3.6. "Science vs. Internet" is a false choice

Affordable broadband is crucial to almost all aspects of 21st century work and life, and some communities welcome satellite broadband. However, we must not assume that LEO satellite constellations are the only option; industry and agencies must develop a meaningful assessment of viable alternatives to satellite broadband, including ground-based fiber, from the perspectives of cost, infrastructure and environmental impact.

3.3.7. Better international regulation and globally coordinated oversight/enforcement

We need coordinated international regulation of the satellite constellation industry with oversight and enforcement, in contrast to the current regulatory maze of siloed issues enabling business as usual. Most of the constituencies polled by the Community Engagement WG want industry to slow down until meaningful solutions can be developed in consensus, involving youth and communities. The fallout from unregulated unchecked satellite constellation launches includes dramatic predicted increases in *all* of the following: space debris, radio frequency interference, orbital traffic and collisions, environmental fallout in the upper atmosphere or oceans after satellite decommissioning, and global sky brightness (not just individual satellite constellation streaks) washing out fainter stars or meteors and undermining dedicated dark sky parks and preserves.

Lastly, the Community Engagement WG views the SATCON2 workshop as the beginning, rather than the end, of a long overdue conversation that was prompted by satellite constellations, but extending to far broader issues of preserving space and the night sky as a scientific, environmental and cultural commons for humanity. The Community Engagement WG urges active engagement and long-term relationship-building amongst industry, leadership, all space actors and communities representing the diversity of stakeholders in our shared skies so we can co-create an inclusive, ethical, and sustainable approach to space.

3.4. Policy Working Group

The Policy WG had the far-reaching charge of reviewing existing national policies and regulatory frameworks.

3.4.1. International Law and Treaties

The Outer Space Treaty (OST[4]) is a legal instrument that is binding on the States that have signed and ratified it (110 ratifications and 23 signatures to date). The foundational principle of the OST and related UN space treaties, namely the freedom of exploration and use of space, has been recognized as customary international law, binding *all* States[5]. Article I states that "*[t]here shall be freedom of scientific investigation in outer space*" and that "*States shall facilitate and encourage international co-operation in such investigation.*" This aspect is exceptionally relevant to mitigating the impact that satellite constellations may have on astronomy, which could be partially mitigated with a continuous exchange of information and data. Article IX of the OST suggests that the US and other parties to the OST have an obligation to implement activities in space with due regard to the corresponding interests of other States in respect of potential light pollution created by satellite constellations.

Article II of the OST establishes that "*Outer space, including the Moon and other celestial bodies, is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means.*" The conditions for a safe, stable, and sustainable environment should not ignore considerations regarding the impact that space activities, albeit coordinated, can have on ground-based activities. The legal principles contained in Article VI of the OST, namely (a) State responsibility for national space activities, including those pursued by nongovernmental entities; and (b) authorization and continuing supervision of such activities by a State, provide two important safeguards for the conduct of space activities by non-governmental entities of a State. The US position has always been that private agencies would not be free to engage in space programs without governmental permission and continuing governmental supervision. A good starting point would be to conduct due diligence concerning the activities of commercial satellite operators, specifically regarding the impact of in-orbit operation of such activities.

3.4.2. US National Law

A variety of existing local, state, and national regulations and laws, coupled with the policy rationales for those measures, support the inclusion, as a condition of licensing commercial satellites and in particular satellite constellations, of an obligation to reduce the detrimental effect of such satellites on astronomy to the greatest degree practicable. Nineteen US states, plus Washington DC and Puerto Rico, have enacted laws to address light pollution. Federal agencies are now also taking affirmative steps to protect the sky at night from light pollution. The federal system of protected lands has grown, and agencies have come to recognize that a naturally dark, star-filled sky is an intrinsic part and critical aspect of the park or wilderness experience. Consequently, an effort to protect the beauty of the skies can, by inference, be considered to require the protection of the astronomical value of the skies.

The National Space Traffic Management (STM) Policy articulates the principles for a safe, stable, and sustainable operational space environment. The National Oceanic and Atmospheric Administration (NOAA) and the US Federal Aviation Administration (FAA) have recently revised their policies to take these STM principles into account, as did the US Federal Communications Commission (FCC) as part of their licensing considerations. There are three implications for licensing requirements. One is the precedent that these agencies can and do consider at least one aspect of in-orbit operations as a condition of licensing. Another is that aggregate effects can and should be taken into account, relevant to the cumulative impact of all orbital material in creating streaks of sunlight compromising observations, particularly for federally mandated missions like planetary defense. The third is that the FCC can pursue regulations that address perceived issues of the space environment without invoking or relying explicitly on environmental statutes like NEPA.

3.4.3. Orbit as Environment

Article III of the OST makes clear that States must carry out activities in outer space in accordance with international law. A 2018 report prepared by the Secretary General of the UN concluded that the prevention principle — the prevention of transboundary harm to the environment — is a well-established rule of customary international law. The UN report further concluded that the prevention principle creates a duty to undertake an Environmental Impact Assessment prior to engaging in activities which pose a risk of transboundary harm. As established by SATCON1, large satellite constellations create an environmental impact due to the light pollution generated as a result of the reflectivity factor of the spacecraft.

US law also considers the effect of human activity on the natural environment. A defensible argument is that NEPA is intended to cover all of Earth, its orbital environment and all other celestial bodies. The FAA construes NEPA broadly and indicates, among other things, that it recognizes light emissions as possibly in the environmental impact category. The FCC, which licenses satellite constellations, does not consider its licensing activities to require Environmental Impact Statements.

We note that the processes inherent to the application of NEPA address a concern articulated in the Community Engagement report. Consultation is required with impacted stakeholders, which could be extended to Indigenous communities with respect to their cultural relationship with natural dark skies. That process could then satisfy some expectations of the UN Declaration on the Rights of Indigenous Peoples (UNDRIP). We also note that the practical production of a full Environmental Impact Statement can be a costly and time-consuming endeavor, of concern to industry in a highly competitive environment.

3.4.4. Industry Perspective

The Industry Subgroup included discussants from SpaceX, Amazon/Kuiper, OneWeb and OneWeb/Airbus, Telesat, AST & Science, and the Satellite Industry Association. The context was to ensure that satellite operators with a sense of corporate responsibility had access to sufficient insight into astronomical concerns, analytical tools and testing, and cross-industry collaboration for information sharing on mitigation techniques to enable them to develop satellite systems mindful of their effect on astronomy. The conclusions do not represent official corporate policy, but rather the continuation of needed technical discussion between industry and the astronomical/dark sky community. They are also an expression of industry intent to be responsive to the technical recommendations of SATCON1 to the extent that solutions are possible and practical, and to generate broader awareness of the impact of their operations on observations and practices dependent on a traditional dark sky.

The Industry Subgroup concluded that satellite operators were more likely to adopt voluntary practices or mitigation tools if they engaged with astronomers early in their project cycle, before spacecraft designs were finalized and when modifications to architectures, spacecraft design or operations could be introduced at less cost or schedule impact. Further, the group concluded that more work was required to ensure that analytical tools, test facilities and observational data are widely available to satellite operators, and are cost-effective, so that their adoption does not disrupt either budgets or schedule for their project.

All satellite projects should be given guidance on minimizing reflectivity. They should be encouraged to minimize nadir-facing specular surfaces and maintain robust orbital attitude control to minimize flares and glints, including deorbiting their satellites as soon as practicable when the satellites reach their end of mission. Operators are recommended, as a first step, to share and publish their experience and lessons learned across the community, in order to build understanding of mitigation design techniques and foster innovation in new concepts. Because the technical and practical inquiry into mitigation techniques is still at an early stage, the Industry Subgroup endorses an outcome-driven focus for any mitigation recommendations and guidelines, rather than overly prescriptive language that stipulates a specific technology or technique.

4. Common Themes

The WGs worked both independently and at times collaboratively, since none of their topics could be fully addressed within a silo. Several common themes relevant to the pursuit of astronomy and preservation of the night sky emerged during the discussions leading up to and during the SATCON2 workshop.

4.1. Urgency

Throughout the SATCON2 discussions, recurring points were made about the abruptness and rapidity with which we are now transforming the night sky. A major challenge here is that industry and academia operate on different timescales. Satellite operators are working quickly and nimbly, within the competitive environment of a new frontier of opportunity, to develop and launch their fleets. In contrast, consensus in academia, especially where diverse stakeholders are involved, is a lengthy and deliberative process. Once consensus is achieved, securing the resources to implement recommendations is often an equally lengthy process of developing proposals, conducting peer review, and working with agencies to initiate funding.

This urgency is underscored by the finding from the Policy WG that astronomy and industry need to engage *early* in the project cycle: projects and design work proceed quickly, and astronomy needs to engage with operators promptly, often at a pace at which it does not typically operate. The Community Engagement WG echoed this need in its “duty to consult” remarks in Section 3.3.1.

Procedural and cultural adjustment among all stakeholders is necessary for combined efforts at mitigation to succeed.

4.2. Investment

The burgeoning use of LEO space creates an enormous unfunded mandate for astronomy. SatHub is a major, multifaceted effort that will require substantial funding, as is the proposed IAU Centre. The Algorithms WG was charged with developing specific recommendations for the required tools but, in the compressed time available to them, was not asked to perform a detailed requirements analysis or FTE estimate. However, even a quick scan of the required tasks makes clear that this is an effort that will require many person-years and millions of dollars. The Community Engagement WG invested substantial time engaging and facilitating discussions with its diverse member group; continuation of these conversations requires long-term support for individuals specifically tasked to do so. And development of policy requires lengthy deliberation, aided by substantial support and input from legal counsel.

Thus far, interactions between astronomy and industry on the satellite constellations issue have been carried out *pro bono* in the “spare time” of individuals associated with relevant committees or associated with affected observatories or institutions. While this has been adequate initially, it is not sustainable as new issues are identified and more operators begin developing and launching satellites. And it is impossible to contemplate SatHub or the IAU Centre operating with anything less than a robust dedicated staff that is well-supplied and well-supported. Since the launch of the first tranche of Starlinks in May 2019, SpaceX has invested considerable time and effort in redesigning and darkening their satellites. Analogous investment must come from astronomy and dark-sky interests if successful and meaningful collaborative work is to continue.

4.3. Conflict vs. Collaboration

One of the findings in the SATCON1 report is that the only way to eliminate the impact of satellites on astronomy is to not launch them. This is not a pragmatic position, just as “Don’t use LEDs outdoors” would not have been pragmatic twenty years ago. We are entering a new era in the use of space, one which will see the rapid growth of satellite fleets, with all the impacts — known and unknown — that this will entail. It is the landscape in which we now live. Tens of thousands of satellites in LEO will inevitably create negative impacts for ground-based astronomy, for ground-based amateur, environmental, and cultural stakeholders, and possibly for space-based interests in comparable orbits, all of which will play out in an arena poorly equipped with policy to manage them. The canvas for unintended consequences and conflict is solidly in place.

Throughout SATCON2, the importance of continuing collaborative work between all stakeholders with highly diverse missions and motivations was manifest. The Observations and Algorithms WG recommendations require that astronomy and industry be in close and regular collaboration henceforth. The Community Engagement WG noted that better international regulation with globally coordinated oversight and enforcement is essential, and the Policy WG addressed this issue in detail. As will be clear in the full WG reports, consensus was often but not always achieved, and disagreements arose. The SOC is unanimous that this is to be expected, but the SOC also views SATCON2 as only the start of a necessary, concerted collaborative effort to address the ongoing transformation of the night sky, engaging the broadest set of interests in moving forward.

5. Concluding Remarks

The steady and now increasingly rapid growth of the number of satellites in LEO has the potential to transform the appearance of the night sky. While individual satellites can likely be designed to be invisible to the unaided eye, their trails will be easily visible to even

entry-level amateur astronomy equipment and will be billions of times brighter than the sensitivity of major research facilities. In addition to the trails, diffuse brightening of the entire natural dark sky by scattering of reflected sunlight from satellites, up to a factor of 2–3 according to some calculations, is an increasingly real possibility. Beyond astronomy, there may be a variety of environmental impacts, including acceleration of climate change through upper atmosphere deposits, degradation of ocean and land health at sites of launches and re-entry, and increasing density of orbital debris. We are on the threshold of fundamentally changing a natural resource that since our earliest ancestors has been a source of wonder, storytelling, discovery, and understanding of ourselves and our origins. We transform that at our peril.

The SATCON2 SOC appreciates the engagement in addressing these issues by the several satellite operators who participated in the workshop, and we hope that this example is followed by other operators entering this arena. We acknowledge that the astronomy community needs an entity tasked to respond to queries from industry promptly and helpfully.

The SOC calls for immediate, well-funded, comprehensive, and collaborative work to accomplish the activities set out by our WGs in Section 3 above. The implications of the industrialization of space reach far beyond astronomy and aerospace, and it is our collective obligation to address them.

Acknowledgments

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Footnotes

1. Scientific Organizing Committee ↩
2. International Astronomical Union ↩
3. Two-Line Element ↩
4. Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, 1966, https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/outerspacetreaty.html ↩
5. https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/status/index.html ↩